HAWAII AGRICULTURAL EXPERIMENT STATION
HONOLULU, HAWAII

Under the supervision of the
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THE HAWAIIAN TREE FERN AS A COMMERCIAL SOURCE OF STARCH

BY

J. C. RIPPERTON, Chemist

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J. C. Ripperton, *Chemist*

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INTRODUCTION

Many generations ago the natives of Hawaii discovered the value of the tree fern as a source of food. They found that they could use the tree fern in place of the taro and the sweet potato, which constituted their favorite and staple food crops; and, likewise, that they could live indefinitely upon a diet of tree fern and wild game when they were defeated in battle and driven from the seashore to the mountains. Usually, they stripped the trunk of the bark[1] and baked the starchy core in an underground oven. It is not unlikely that the natives obtained starch from the tree fern, since they were familiar with the art of extracting it from the arrowroot.

Many attempts have been made within recent years to produce tree-fern starch on a commercial scale. None of these proved successful, however, due to insufficient capital for the proper development of the product, until 1920 when tree-fern starch was successfully manufactured and appeared on the local markets in a form suitable for use as food and for laundry purposes.

Although some feared that the new industry would soon destroy the beautiful tree-fern forests, the Hawaii Experiment Station received many requests to aid in developing it. To satisfy those who looked unfavorably upon the industry, the station made a preliminary investigation to determine the effect on the forests and on water conservation of cutting over tree-fern areas. As a result of

[1] In this publication the word " bark " is used to describe all that portion of the tree-fern trunk except the central starch-containing core.

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the investigation, it was found that even a considerable thinning of the ferns for starch production is not noticeable. The tree fern falls to the ground of its own accord, or is easily pushed over, upon reaching maturity, and since only the mature trees are utilized for starch making, relatively few trees per acre would be cut for this purpose.

A rather extended program of work was therefore outlined, (1) to determine the feasibility of planting tree ferns on cut-over areas for the establishment of permanent-producing areas, and (2) to make a study of the properties and uses of tree-fern starch. When it was found that the rate of growth of the tree fern is too slow to make it commercially practicable to replant the fern and the necessity of building roads and fences to get the necessary raw material became apparent, hopes were abandoned of establishing the industry on a large and permanent basis in Hawaii. It is not unlikely, however, that the industry might be made a permanent one under the economic conditions existing in other tropical countries in which certain species of the tree fern are indigenous.

This bulletin, reporting the results of certain observations, together with data on the Hawaiian tree fern as they apply to its use as a source of starch, has been prepared because of the scientific interest which the industry has aroused and because of the potential importance of the tree as an emergency crop for the island population in case of interruption of shipping.

BOTANICAL DESCRIPTION

Rock [2] lists eight species of Cibotium, two occurring in Guatemala, one in southern Mexico, one in the monsoon districts of east Asia, one in the Philippines, and three that are peculiar to the Hawaiian Islands. The following botanical description of the two most important species in Hawaii may be of interest.[3]

Cibotium menziesii.—* * * Stipes green, stout, with a ventral and two lateral furrows, tuberculate and shaggy at the base with a straightish and long brownish-yellow glossy pulu which changes higher up into stiff, long blackish hair, and as such often covers the entire stipes; frond with stipes 18 to 36 dcm. or more long and 9 to 15 dcm. or more broad, pyramidal-oblong, coriaceous, naked underneath or sometimes with minute furfuraceous dots; the rhachis asperous with scattering tubercles; pinnæ with a stipe of 25 to 50 mm., oblong, 4.5 to 7.5 dcm. long, bearing 18 to 24 pairs of free pinnules besides the pinnatifid apex; most pinnules shortly stipitate, linear lanceolate, acute, cut halfway or more, often to the rhachis at the base, into oblong rounded or entire segments, which are separated by broad sinuses; veinlets very prominent, simple or forked; sori 8 to 14 on a lobe, also fringing the sinus. Involucre corneous, large, a little more than 1 mm. to nearly 3 mm. in width, the outer valve fornicate and large, the inner flat and narrower.

C. chamissoi.—* * * Stipes 12 to 24 dcm., brownish, smooth, clothed at the base with a pale fawn-colored lustreless, matted or cobwebby pulu, furfuraceous or naked above; frond 12 to 24 dcm. long, chartaceous, the under face green or dull glaucous and generally covered with a pale cobwebby pubescence; lowest pinnæ 4.5 to 7.5 dcm. long, with 24 to 28 pairs of pinnules, these shortly stipitate, linear lanceolate 12.5 to 15 cm. by 16 to 20 mm. acute, the lower ones cut to near the rhachis into oblong, straightish, rather obtuse segments with narrow sinuses, the basal segments entire and not deflected; veinlets little prominent; sori 8 to 14 to a segment, the involucre small about 1 mm. wide, chartaceous.

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[2] Rock, J. F. The indigenous trees of the Hawaiian Islands, p. 89.
[3] Rock, J. F. The indigenous trees of the Hawaiian Islands, pp. 91–93.

Hillebrand[4] lists another species, *C. glaucum*, but states that it is rather rare.

Cibotium chamissoi, or "Hapu" as it is popularly known, is easily recognized by its yellow pulu or hair and its comparatively short, stocky growth. In many forests it constitutes more than 50 per cent of the entire tree-fern growth. The trunk sometimes attains a height of 16 feet, but usually does not exceed 10 feet. The diameter of the trunk is usually 8 to 12 inches. (Pl. I, fig. 1.) *C. menziesii*, or "Hapu Iii," is distinguished by the brownish or blackish pulu which covers the stipes and fills the crown. Occasionally it attains a height of 40 feet and frequently a diameter of 3 feet. (Pl. I, fig. 2.) Another species, commonly known as the "Meu," is easily recognized in the Hilo district by its very slender trunk, smaller fronds, dull, lusterless, rather scant, yellowish-brown pulu, and nearly naked stipes. (Pl. I, fig. 3.) The "Amau" (*Sadleria cyatheoides*), although a different genus of tree fern, is also of interest since it is exceedingly common in occurrence and has a starchy core.

OCCURRENCE IN HAWAII

The tree fern is found in all parts of Hawaii where there is an annual rainfall of 100 inches or more. It grows on nearly all the mountains, but occurs in dense forests only on the islands of Kauai and Hawaii. On Kauai the forests are too inaccessible to be of importance for starch production, but on Hawaii they occur in almost unbroken stretches from sea level to an elevation of 6,000 feet or more. These long stretches are reached both by rail and automobile roads running from Hilo to the Kilauea Volcano. The windward slopes of the Mauna Kea and Mauna Loa Mountains are one continuous tree-fern forest, the belt extending from the Puna district to the Hamakua district being about 10 miles wide and 40 miles long. In general it is estimated that there are 400,000 acres of tree-fern forests on the island of Hawaii alone. A very large part of this area is within the forest reserve or on Government-owned lands, from which it is illegal to cut the tree fern. There are, however, many thousands of acres of privately owned land on the island of Hawaii, which in its present state is of little value because the dense growth of tree ferns unfits it for pasture and the heavy covering of leaf mold keeps the soil too wet for general agricultural purposes. The owners of these lands regard the tree fern as a pest and would welcome any means of removing it.

STUDIES OF METHODS OF PROPAGATION AND GROWTH

It was felt that before the tree-fern starch industry could be established on a large scale in Hawaii some feasible method must be found for providing a permanent source of the raw material. Many of the tree-fern areas are hard to reach, and it is almost impossible to secure the raw material at any great distance from the established roads because of the rough topography and the heavy leaf mold. Moreover, the cost of getting the raw material from the depths of the forest, when the supply adjacent to the highway became exhausted, would reach a prohibitive figure.

[4] Hillebrand, Wm. Flora of the Hawaiian Islands, p. 547.

The possibility of securing a large tract of tree-fern forest for the establishment of a permanent starch-producing area was therefore considered. Such an area would have to be strongly fenced to keep out cattle and hogs, and roads would have to be built at intervals, with subsidiary donkey trails, to permit of the tree-fern logs being carried out. The purchase of such a tract would be feasible if it could be shown that the tree-fern growth could be successfully maintained by natural methods of propagation, or by planting cuttings from different parts of the fern, thus assuring a permanent and increasing supply of readily accessible raw material. It was therefore decided to learn whether parts of the tree fern could be successfully planted on cut-over areas, and whether the rate of growth would be sufficiently rapid to justify the cost entailed in establishing and maintaining such an area.

The first step in the solution of the problem seemed to be the acquisition of a detailed knowledge of the character and habits of the tree fern. Since the literature was found to contain only certain botanical descriptions, a series of observations was begun of its natural methods of propagation and growth.

NATURAL METHODS OF PROPAGATION

The tree fern reproduces itself in two general ways—(1) by spore germination (Pl. II, fig. 1) and (2) by lateral shoot development (Pl. II, fig. 2). The spores are borne on the underside of the fronds. Old tree-fern trunks and moss furnish excellent seed beds for spore germination, and land that is undisturbed by cattle and wild hogs is frequently literally covered with the tiny ferns. Their growth is, however, very slow.

Propagation by lateral-shoot development on the trunks of mature trees is much more rapid than by spore development. One to three such shoots are found about each tree in varying stages of development in the native forests. These increase to as many as 15 when the tree fern has been injured, or the soil about it trampled upon by animals. The shoots begin to develop when the parent tree ceases to grow or falls to the ground. It is not uncommon to find, even on young, vigorous trees, one or two shoots which are almost as large as the parent. The shoot soon establishes its own root system and in a short time becomes independent of the original fern. The crown continues to grow after the tree has fallen, the fronds gradually turn in a vertical direction, another root system is established at the new base, and growth proceeds almost uninterruptedly.

PLANTING TREE FERNS

It is a well-established fact that tree ferns can be successfully propagated from crowns and lateral shoots which spring from the trunk, as well as from spores, but since the entire inner core of the trunk is used for starch, planting would not be feasible if sections of the trunk were necessary for the production of new growth; and it was not known whether the undeveloped lateral shoots which are found on the average tree would develop if removed from the trunk. Three experimental plats were therefore

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Fig. 1.—Typical Specimen of Cibotium chamissoi, Showing Its Rough Bark and Comparatively Short, Stocky Trunk

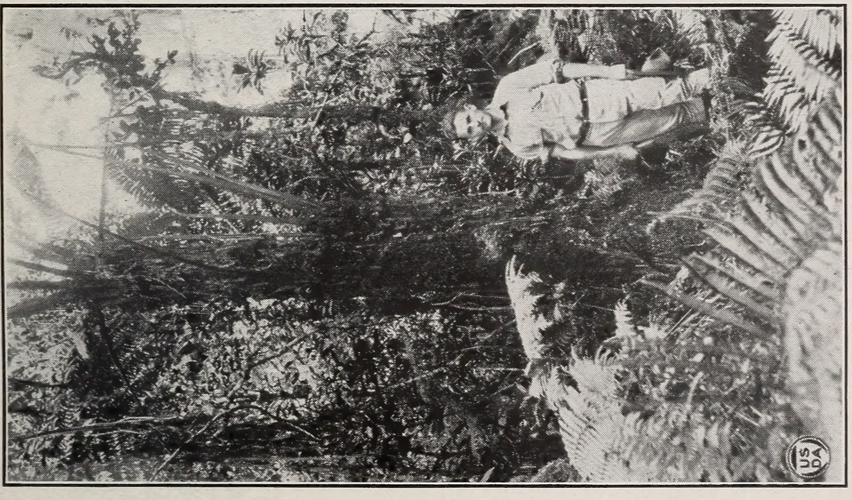

Fig. 2.—Typical Specimen of Cibotium menziesii, Showing Its Smooth Trunk and Relatively Great Height Compared with Its Diam-

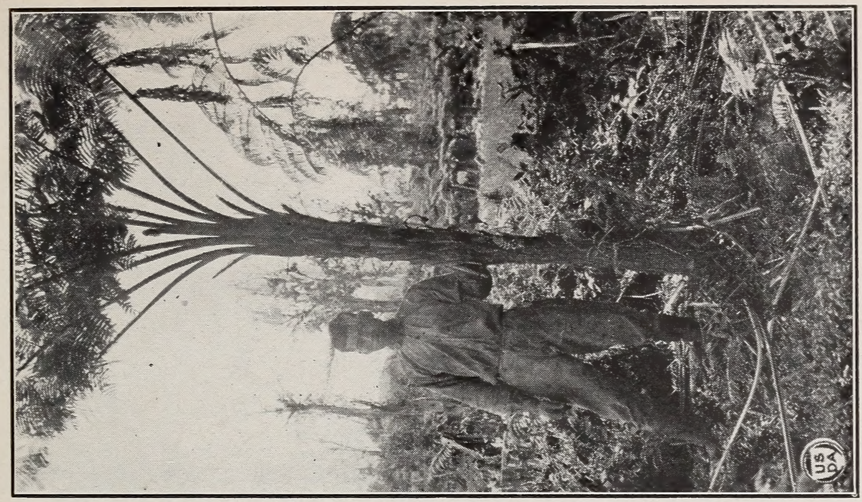

Fig. 3.—Typical Specimen of Cibotium sp., Known Locally as "Meu." Note the Very Small Trunk and Fronds

FIG. 1.—NATURAL PROPAGATION FROM SPORES. AN OLD TREE-FERN TRUNK LITERALLY COVERED WITH TINY TREE FERNS. THE SPORES ARE FOUND ON THE UNDERSIDE OF THE MATURE FRONDS

FIG. 2.—CROWNS AND LATERAL SHOOTS USED FOR PROPAGATION EXPERIMENTS

established at different altitudes for the purpose of determining the feasibility of planting the tree fern for starch production. These experiments were carried on at the following places:

(1) Volcano plat (3,500 feet elevation) on the McKenzie ranch, at 29 Miles, Volcano Road. This plat is adjacent to the forest reserve on windward Hawaii. It is used as a pasture and contains a scattered growth of tree ferns. The experiment was made here to determine whether the tree fern could be successfully planted on areas that had been denuded of their original growth and on which there was no shade.

(2) Glenwood plat (2,000 feet elevation), located 2 miles above Glenwood on the Volcano Road. This plat was selected because it is in the midst of an excellent tree-fern growth and is easy of access. (Pl. III, fig. 1.)

(3) Mill plat (2,200 feet elevation), located 4 miles north of the Volcano Road at 18 Miles. This plat is in an area now being cut over for starch production. It represents ideal conditions as to shade, soil, and the like under which the tree fern would be planted.

The plantings included crowns, and large, small, and medium sized lateral shoots of each of the several species. Comparative plantings were made to determine the effect on growth of varying the length of the starch core attached to the cuttings, drying the cut surfaces before planting, planting at different depths, in different kinds of soil, and at various altitudes. Since this work was discontinued before the effect of these various factors on the growth of the tree fern was determined, the general conclusions of the experiment only are given.

Under true forest conditions, such as existed at the Mill plat, all crowns and lateral shoots were successfully propagated, regardless of variety, size, method of planting, or length of attached starch core (Pl. III, fig. 2). Fully 70 per cent of the small, undeveloped shoots, which had been detached from the starch core of the parent tree, grew when planted.

The plantings made in the open pasture on the Volcano plat started vigorous growth during the cool, moist winter months, but died during the dry, hot summer months. Other plantings, made in a shaded area closely adjacent, lived and gave results similar to those obtained at the Mill plat.

In brief, it is concluded that, under true forest conditions, an average of three successful plantings or sets can be made from each felled tree fern; and that the starch core of the parent tree need not be attached to the plantings or sets. It seems evident, therefore, that a cut-over area could be successfully replanted without interference with starch production, and that the density of growth could be gradually increased to a maximum.

METHODS OF GROWTH

In order to determine how fast the tree-fern trunk grows, it was necessary to learn the nature and method of its growth. For this purpose a study was made of the lateral growth of the trunk, the vertical growth within the trunk, growth at the base of the trunk, and growth at the top of the trunk.

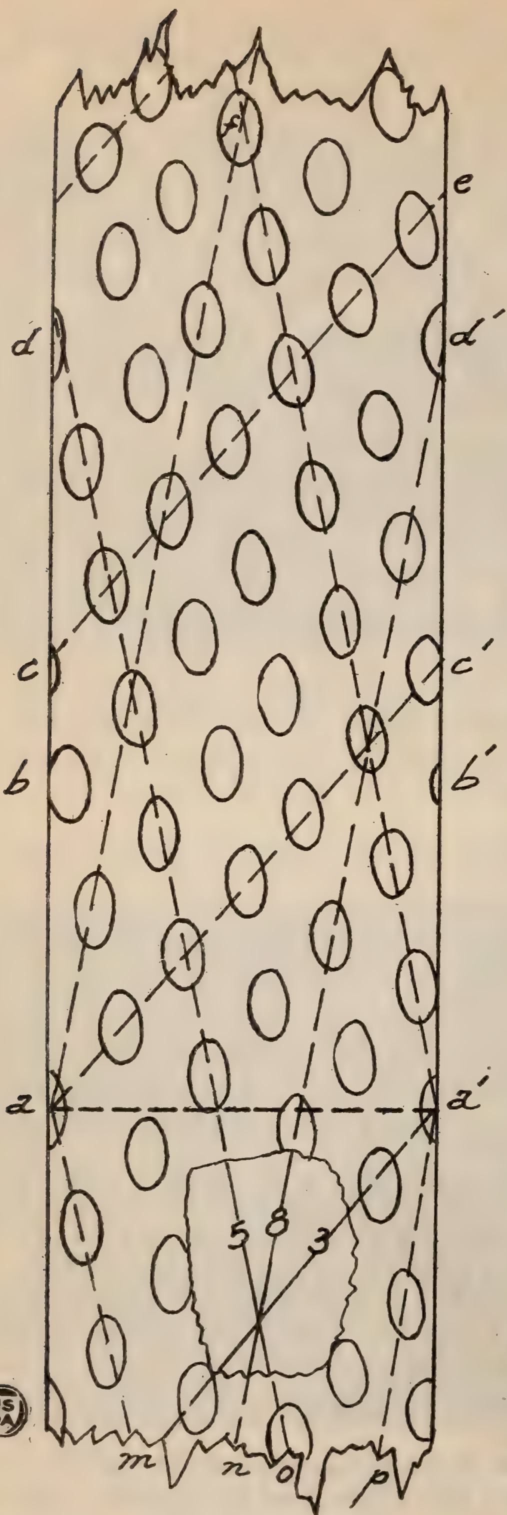

FIG. 1.—Graph showing the spiral arrangement of tree-fern fronds.

The lateral growth of the starch core would seem to be negligible since it is immediately surrounded by a very hard, brittle covering measuring one-fourth to one-half inch in thickness, and apparently is incapable of further growth or expansion. In five out of eight trees the starch core was found to be appreciably larger at the top than at the bottom of the trunk, which shows that as the tree fern grows from a small lateral shoot or spore to a large size, the core grows correspondingly larger at the top only; and that the part first formed does not increase in diameter. Many trees are found in which the starch core tapers almost to a point at the base. Trees grown from very large lateral shoots show little tapering of the core, and trees resulting from the turned-up crown of a large fallen tree show none at all. It is true that the gross diameter of the tree, especially of the species *Cibotium menziesii*, increases with the growth of the tree, but this increase is due entirely to the increase in abundance of the air-feeding roots making up the outer bark of the tree.

That there is no vertical growth within the trunk, except at its apex, is shown by the fact that the vertical distance between frond pits on the same spiral is the same regardless of whether the measurements are made at the bottom or at the top of the trunk. This vertical distance would show a gradual decrease from

bottom to top if there were an appreciable growth within the trunk.

Many species of monocotyledonous trees show an increase of growth at the base of the trunk, as is frequently evidenced by the dead roots which are found covering 2 or 3 feet of the base of the tree trunk. That this is not the case with the tree fern is shown by the uniform occurrence of pits from which the fronds once protruded along the entire length of the trunk. It would seem, therefore, that such growth in the tree-fern trunk is negligible.

The method of growth at the top of the trunk, however, is very striking. In the early spring new fronds or leaves develop, a complete circle of new fronds averaging five in number emerging from the heart of the crown at practically the same stage of development (Pl. IV, fig. 1). These fronds attain full size within about three months after the time of their appearance and remain on the tree from 18 to 24 months: An occasional immature frond can be found on the tree after the first five fronds develop.

METHOD OF DETERMINING THE RATE OF GROWTH

When the outer bark is stripped from the tree fern, or when an old log in which the starch core has decayed is split open, the fronds are observed to be arranged in definite spirals. Figure 1 represents graphically the surface of a tree-fern log from which the outer bark has been removed to disclose the location of the frond attachments, regarded as a hollow cylinder cut lengthwise and laid out flat. The ellipses represent frond pits or the openings in the bark from which the fronds protruded.

A number of different spirals are apparent in the diagram. Among the more obvious are those parallel to the lines *o–d′*, *n–d′*, and *m–a′*, respectively.

The arrangement of fronds was found to be the same on a large number of stripped tree-fern logs, and the spiral combination of 3, 5, and 8 fronds could readily be counted. The only difference noted was in the direction of growth of each spiral, which was clockwise on some trees and counterclockwise on others.

Since probably a circle averaging five fronds is developed each spring, each of the five spirals would seem to be annually represented by one frond. If this were true, or if the average yearly number of fronds per tree showed little variation in the different trees, it would be necessary only to measure the vertical distance between two frond pits on one of the five spirals to determine the annual growth of the tree (Pl. IV, fig. 2).

To determine the correctness of this assumption, the fronds of a number of trees growing at different altitudes were marked with copper tags at each frond-setting period and the trees were visited once a year. Usually, it was not difficult to distinguish the new fronds. The species Hapu (*Cibotium chamissoi*), which is the only one used to any extent for starch production, was selected for this study.

Table 1 gives the annual number of fronds set per tree during four successive years:

TABLE 1.—*Annual number of fronds set per tree (Cibotium chamissoi) during four successive years*

Tree No.	Number of new fronds developed				
	1920	1921	1922	1923	Average
Elevation, 3,500 feet					
1	-----	5	5	3	4.33
2	-----	6	8	7	7
3	-----	4	5	5	4.67
4	-----	7	7	5	6.33
5	-----	5	7	5	5.67
6	-----	6	8	5	6.33
7	-----	-----	5	5	5
8	5	4	7	5	5.25
	-----	-----	5	7	6
	-----	5	5	4	4.66
Average	-----	-----	-----	-----	5.52
Elevation, 2,200 feet					
1	5	5	6	5	5.25
2	5	5	7	5	5.5
3	6	4	6	5	5.25
4	5	4	4	6	4.75
5	6	5	6	5	5.5
6	5	7	6	5	5.75
7	5	3	5	5	4.5
8	6	5	-----	-----	5.5
Average	-----	-----	-----	-----	5.25

While the data given in Table 1 do not conform to the theory that each of the five spirals is represented annually by a frond, they do verify the observation that the average annual number is a fraction over five, and show that this number is practically the same regardless of altitude.

It would seem, therefore, that the rate of growth of the tree fern could be closely determined simply by measuring the vertical distance between any two successive frond pits of the same spiral and by multiplying this distance by 5.39 and dividing by the spiral number, that is by 3, 5, or 8. For example, if this distance on the 5 spiral averaged 4 inches, the yearly vertical growth would be $4 \times \frac{5.39}{5}$, or 4.31 inches; or, if measured on the 3 spiral, it was 2.4 inches, the yearly vertical growth would be $2.4 \times \frac{5.39}{3}$, or 4.31 inches.

In order to ascertain the average vertical distance between the frond pits, eight trees (*Cibotium chamissoi*), growing near the Mill plat, were stripped of their bark and measurements were made of their diameter, length, weight, and the like. These data, together with the rate of growth as computed by the foregoing method, are given in Table 2:

FIG. 1.—TREE FERNS GROWN FROM CROWNS AT GLENWOOD SUBSTATION (HAWAII)

FIG. 2.—TREE-FERN HEDGE GROWN FROM CROWNS

FIG. 1.—METHOD OF GROWTH OF THE TREE FERN. EACH SPRING AN AVERAGE OF FIVE NEW FRONDS APPEAR

FIG. 2.—SPIRAL ARRANGEMENT OF FRONDS. TREE-FERN TRUNK FROM WHICH PART OF OUTER BARK HAS BEEN STRIPPED. THE NUMBERS REFER TO THE SPIRALS SHOWN DIAGRAMMATICALLY IN FIGURE I

TABLE 2.—*The rate of growth of the tree fern and amount of starch core it produces annually* [1]

Tree No.	(a) Weight of starch core	(b) Length of starch core	Diameter of starch core: Top	Diameter of starch core: Bottom	(c) Vertical distance between successive fronds: 5-spiral	(d) Annual vertical growth [2]	(e) Estimated length of time required for growth [3]	(f) Starch core produced annually [4]
	Pounds	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Years*	*Pounds*
1	34.5	66	5.4	3.8	4.12	4.44	14.9	2.31
2	64	65	7.3	6.7	4.06	4.38	14.8	4.32
3	76	80	5.4	6.1	4	4.32	18.5	4.11
4	87	128	4.8	5.4	4.57	4.93	26	3.35
5	58.5	72	6.1	4.1	4.5	4.85	14.8	3.95
6	72.5	101	5.7	4.5	3.49	3.76	26.9	2.7
7	15	33	4.1	4.5	4.13	4.45	7.4	2.03
8	11	41	3.8	2.43	3.41	3.68	11.1	.99
Average						4.35		2.97

[1] The 5-spiral measurements are used in these computations because the coefficient of error in measurement is less than in case of the 3-spiral.
[2] c multiplied by 5.39, divided by 5.
[3] b divided by d.
[4] a divided by e.

Table 2 shows that the average vertical growth of the tree fern is fairly uniform and averages 4.35 inches annually, and that the annual production of starch is subject to wide variations due to difference in diameter of the starch core. The annual increment in starch core averages 2.97 pounds.

Sections of the bark of a large number of trees growing at varying altitudes were slabbed off to permit of measuring the distance between successive fronds for a distance of about 1 foot. The data so secured, while only approximate, would seem to show that the rate of growth of the tree fern is practically constant between sea level and an altitude of 3,500 feet. Measurements of other species of tree ferns showed that they make about the same rate of growth as does *Cibotium chamissoi.*

The very slow rate of growth of the tree fern brings into very serious question the feasibility of planting cuttings of different parts for starch production. It would require at least 20 years to grow a tree fern of sufficient size to cut for starch, since it has been found unprofitable to cut trees having less than a 60-pound starch core. Twenty years is a rather prohibitive length of time, especially for a small industry, to wait for replanted areas to furnish new material.

As a result of the investigations it was concluded that, while the tree fern can be successfully planted on cut-over areas, its rate of growth is too slow to make such a procedure advisable under present conditions.

CHEMICAL COMPOSITION OF THE CORE

Preparatory to analyzing the core the outer fibrous sheath and the hard inner bark were stripped from it. The yellowish-white core was then shredded and the nonreducing and reducing sugars were determined. The methods of analysis recommended by the Associa-

tion of Official Agricultural Chemists[5] were employed in making the rest of the analysis.

The results are given in Table 3, which includes also, for purposes of comparison, the chemical composition of the potato and edible canna, both of which are grown for commercial starch production:

TABLE 3.—*Comparison of the chemical composition of the tree-fern core with that of the potato and edible canna tubers*

Constituent	Tree fern (*C. chamissoi*)	Potato	Edible canna	Constituent	Tree fern (*C. chamissoi*)	Potato	Edible canna
Water	73.39	78.30	72.62	Fiber	1.57	0.40	0.61
Protein	.95	2.20	.98	N-free extract	22.99	18.00	24.28
Fat	.06	.10	.11	Nonreducing sugars	.24		
Ash	1.04	1.00	1.40	Reducing sugars	3.99		

From Table 3 it will be seen that in chemical composition the core of the tree fern is very similar to the ordinary tuber crops, and, as might be expected, it contains rather large amounts of reducing sugars. In view of the peculiar manner of growth of the tree fern, it is very probable that the sugar content varies considerably in the different sections of the core as well as in different seasons.

The tree-fern core is apparently equal to other starch crops as a stock feed. It is eaten readily by cattle and hogs, probably because of its high sugar content. The new, tender fronds form the most important part of the forage for stock pasturing in a tree-fern forest; and the heart of the trunk is also eaten when it can be reached. Were it not for the prohibitive amount of labor required to split open these trunks, the tree fern undoubtedly would have an important place among the stock feeds of the tree-fern forest districts.

The core of the tree is not palatable as human food. It has a peculiar flavor and is rather fibrous. The tender, undeveloped fronds are sometimes cooked as a vegetable, but the core as such has never become of practical importance.

PHYSICAL PROPERTIES OF TREE-FERN STARCHES

Samples of starch were prepared from the species Hapu (*Cibotium chamissoi*), Meu (*Cibotium* sp.), Hapu Iii or Heii (*C. menziesii*), and Amau (*Sadleria cyatheoides*).[6] Microscopic examination and photomicrographs were then made of each. The characteristics of each starch as they appeared when magnified 220 diameters were found to be as follows:

(1) Hapu (*C. chamissoi*). (Pl. V, fig. 1.)

Size, 0.01 to 0.05 millimeter. Varying sizes in about equal proportion; shape, irregular oval, occasionally kidney-shaped, in large sizes, but circular disks, with a few truncated forms in the small sizes; hilum, annular, with a few longitudinal rifts, depressed, usually central in small sizes; rings, complete, very distinct, with a very pronounced ring in most of the larger granules about midway between the hilum and the outer edge; polarizer, very brilliant dark cross at central axis.

[5] Methods of analysis of the Association of Official Agricultural Chemists. Sec. VII, p. 71. Revised to Nov. 1, 1919, Washington, D. C., 1920.

[6] The individuals of each species selected for these samples were as nearly typical specimens as could be found. No botanical identification was made of them, since they exist in comparatively pure strains, and no difficulty was had in differentiating between them.

(2) Meu (*Cibotium* sp.). (Pl. V, fig. 2.)

Size, 0.01 to 0.05 millimeter (long axis); shape, usually elongated disk in the large sizes, but round to oval in the small sizes, and a few truncated and kidney-shaped in all sizes; hilum, usually annular, depressed, eccentric; rings, complete, very distinct; polarizer, distinct cross at hilum.

(3) Hapu Iii or Heii (*C. menziesii*). (Pl. VI, fig. 1.)

Size, 0.01 to 0.04 millimeter; shape, round to oval, occasionally truncated and angular; hilum, annular, central, depressed; rings, very pronounced, concentric, complete; polarizer, very distinct cross at hilum.

(4) Amau (*Sadleria cyatheoides*). (Pl. VI, fig. 2.)

Core, mostly colloidal dextrins, with starch grains of extremely minute size. The starch can not be separated from the grated mass by sedimentation; size, 0.01 to 0.03 millimeter; shape, round to oval; hilum, usually central, annular, depressed; rings, distinct on large granules, and complete; polarizer, well-marked cross at hilum.

The illustrations and morphological descriptions show that the four starches possess many of the same characteristics, the chief differences being in size and shape. Considered from the standpoint of the physical characteristics of the starch granules, each of the four species could be used for starch production. As a matter of fact, the starch of *Cibotium chamissoi* is very much to be preferred to that of the other three species. The starch of both *C. menziesii* and Meu, in addition to being of small diameter, contains such large quantities of dextrins and other colloidal matter as to make the separation of the starch difficult. The starch of *Sadleria cyatheoides* is manifestly unsuitable.

VISCOSITY

Since the viscosity curve of a starch, when transformed by boiling water into "soluble starch," is useful in showing its general properties, determination was made of the viscosity of tree-fern starch, and likewise of corn and arrowroot starches for purposes of comparison. The method of procedure was as follows: Varying amounts of starch were weighed into 100 cubic centimeter flasks graduated at 80° C. with 10 cubic centimeters of cold water. Boiling water was added with vigorous shaking, and the flasks were made up to the mark at 80° C. with hot water. The flasks were then placed in boiling water for one hour without agitation, after which they were quickly cooled to 80° C. with as little agitation as possible, and the viscosity was determined with a Saybolt universal viscosimeter at that temperature. Duplicate determinations by the above arbitrary procedure agreed with fair accuracy. Any variation in procedure, however, caused very large differences in the result. For example, vigorous shaking during cooking decreased the viscosity as much as 50 per cent. Variations in temperature and time of cooking also caused appreciable deviations. The results are graphically given in Figure 2.

The concentration of starch solution necessary to produce a definite hydrogel when cooled was determined by pouring 10 cubic centimeters of the hot starch solution used for determining the viscosity into test tubes one-half inch in diameter. The tubes were placed in water at about 18° C. and allowed to remain unagitated for one hour. They were then inverted. The minimum concentration necessary to keep the mass from flowing down the inverted tube was termed its "gelling strength." The gelling strength of cornstarch, tree-fern starch, and arrowroot starch was found to be 4.25, 5, and 5.25 per cent, respectively.

The above data on viscosity and gelling strength bring out a number of important differences among the starches. The concentrations necessary to cause any appreciable increase in viscosity were 1.5 per cent of arrowroot, 2 per cent of tree fern, and 3 per cent of cornstarch. Above 3 per cent the curve for cornstarch shows a very sharp increase. A 1-gram increment causes an increase in viscosity of 1 to 6, whereas a like increment of tree fern and arrowroot over the concentrations of 2 and 3 per cent, respectively, causes increases of 1 to 3. As the concentration increases, the tree fern and cornstarch curves practically coincide. The arrowroot curve, although

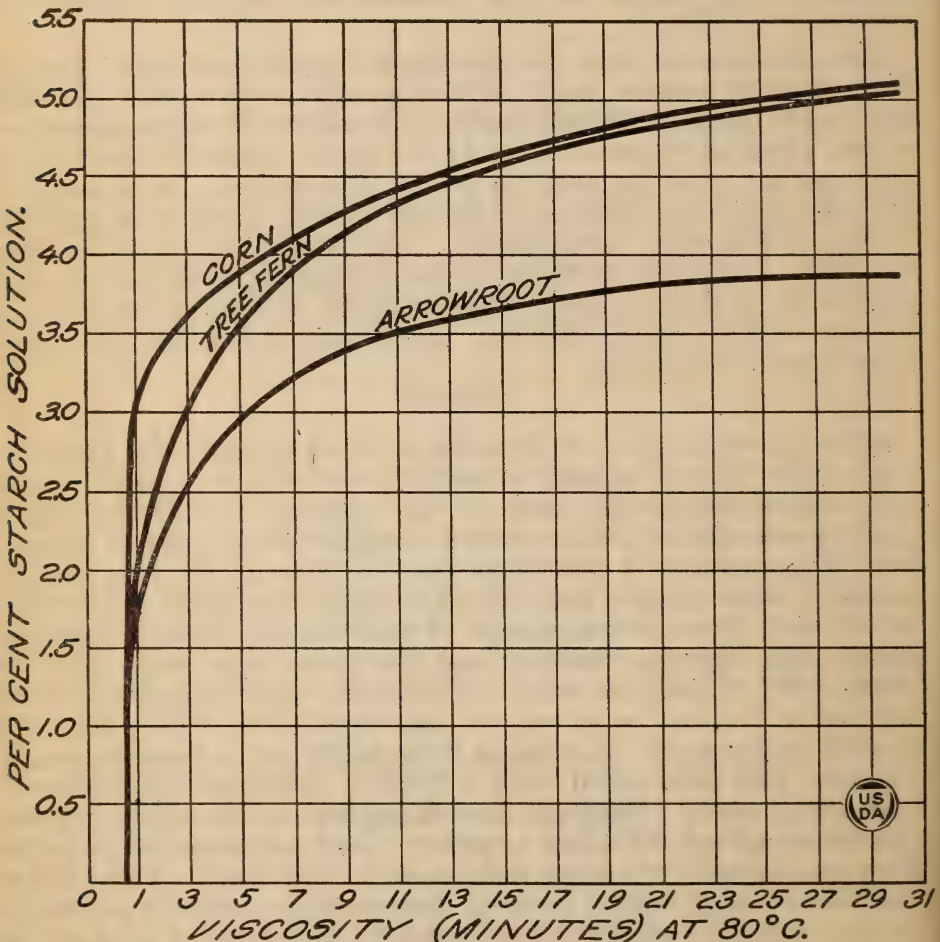

FIG. 2.—Comparison of the viscosity of tree-fern starch and other commercial starches.

showing greater viscosity than that of the tree fern, is of the same general nature.

The gelling strengths of the three starches were in the opposite order of their viscosities. A cornstarch solution with a viscosity of 8.75 formed a stiff gel when cooled, while a tree-fern solution required a viscosity of 27 to form a gel. A 4 per cent arrowroot solution required from three to four hours to pass through the viscosimeter, and yet a 5.25 per cent solution was necessary to form a gel.

The physical qualities and appearance of the three are likewise distinct. Cornstarch forms a tender, clean-cutting, definite hydro-

FIG. 1.—STARCH GRANULES OF CIBOTIUM CHAMISSOI (HAPU). MAGNIFIED 220 TIMES

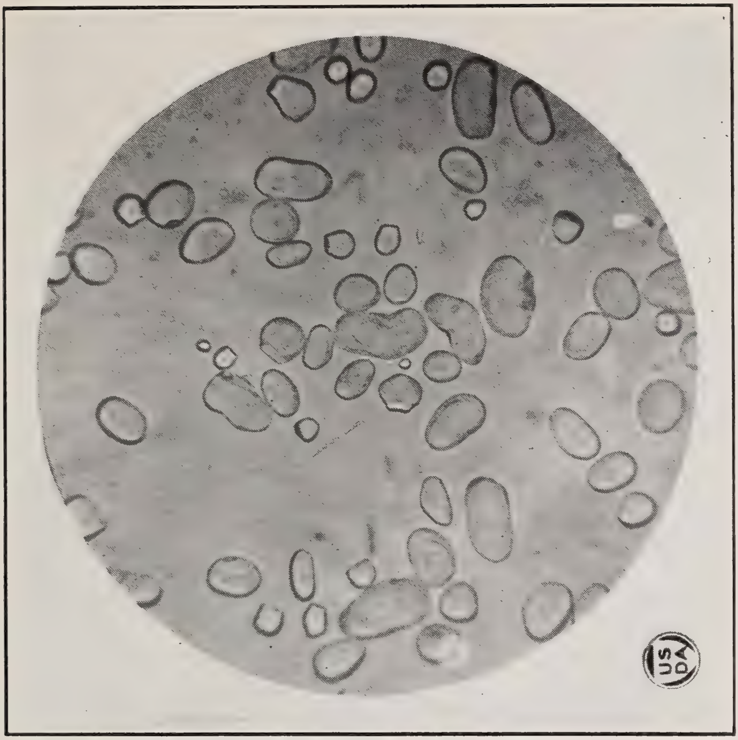

FIG. 2.—STARCH GRANULES OF CIBOTIUM SP. (MEU). MAGNIFIED 220 TIMES

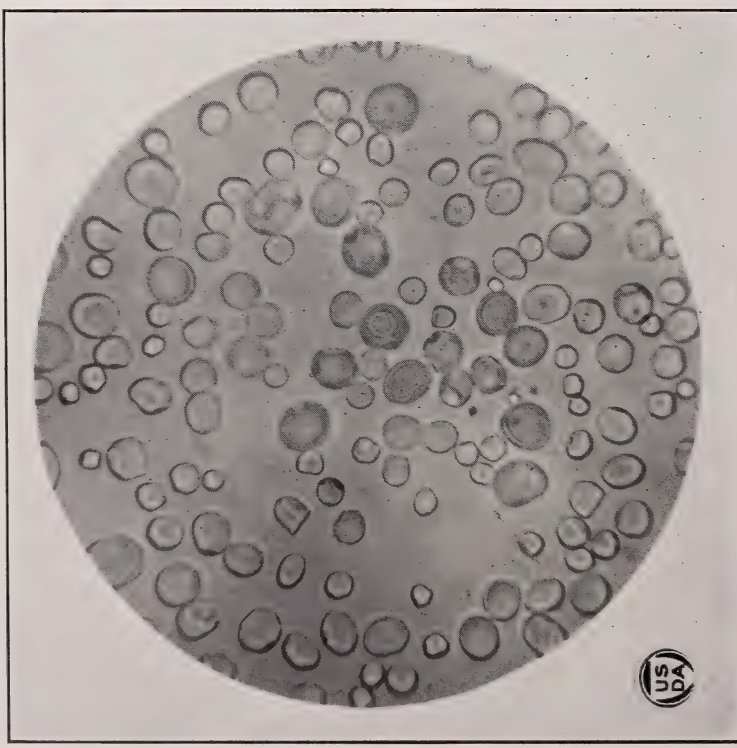

FIG. 1.—STARCH GRANULES OF CIBOTIUM MENZIESII (HAPU III). MAGNIFIED 220 TIMES

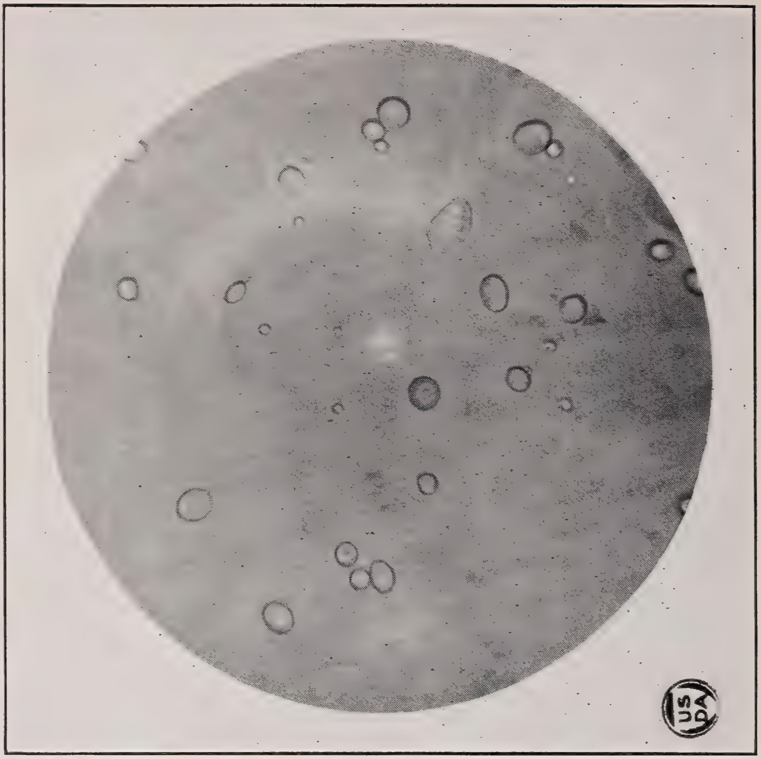

FIG. 2.—STARCH GRANULES OF SADLERIA CYATHEOIDES (AMAU). MAGNIFIED 220 TIMES

FIG. 1.—THE STARCH CORE OF THE TREE-FERN TRUNK, SHOWING THE LARGE STARCH CORE AND THIN BARK OF THE CIBOTIUM CHAMISSOI (LEFT), AND THE SMALL STARCH CORE AND THICK, DENSE BARK OF C. MENZIESII (RIGHT). THE FORMER SPECIES IS THE ONE USED FOR STARCH PRODUCTION

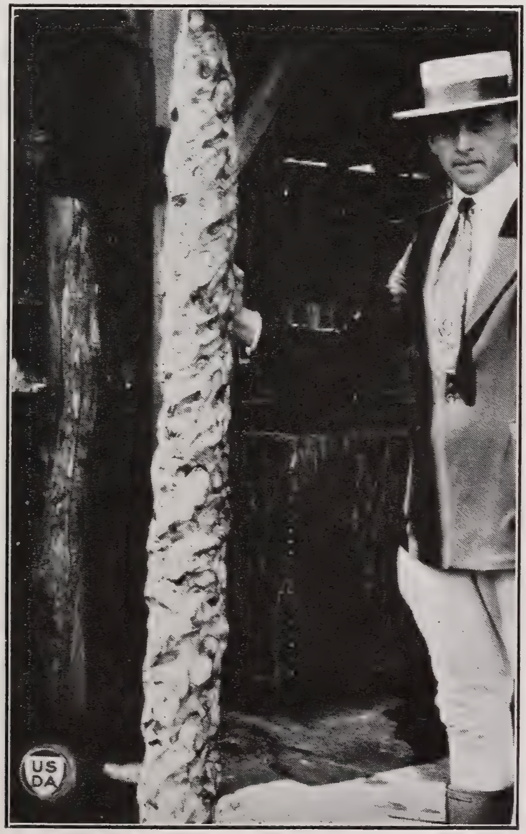

FIG. 2.—AN 80-POUND STARCH CORE WHICH IS READY FOR THE SHREDDER

gel, while the other two starches form what may be termed plastic gels, or simply emulsions having a very high viscosity. The former gel is greatly affected by changes in temperature, concentration, and agitation, whereas the latter are relatively little affected. In appearance, cornstarch gel is opaque, while the tree fern and arrowroot gels are translucent.

USES

Tree-fern starch has been put on the market both as a laundry starch and as a food. It is claimed that only half the concentration necessary for cornstarch is required for tree-fern starch for laundry purposes. Reference to Figure 2 bears out this claim to some extent, since a 2 per cent solution of tree-fern starch has a viscosity equal to 3 per cent of cornstarch, which is about the usual concentration used for laundering.

Since the physical properties of tree-fern starch are similar to those of the arrowroot, the former is being advocated as a substitute for the latter for invalids and infants. Although Figure 2 shows it to have less strength than arrowroot starch has, its cost is only slightly more than cornstarch and only a small fraction of that of arrowroot.

In Hawaii, tree-fern starch is largely used as a mixture with poi.[7] The starch is simply cooked with water and added to the poi. The cost of the poi is materially reduced by adding the starch to it, its flavor is said to be improved, and the rate of fermentation desirably retarded. These claims are substantiated by the fact that practically all Hawaiian institutions using poi now incorporate tree-fern starch with it.

As a food substitute for cornstarch, tree-fern starch is not generally popular. Figure 2 shows that at a concentration of 4.25 per cent, which is about the concentration necessary to produce a cornstarch pudding, tree-fern starch has practically the same strength. As previously noted, however, it is, like arrowroot starch, somewhat sticky and tenacious in comparison with cornstarch, which is tender, and clean-cutting.

In an experiment made to determine the digestibility of various raw starches, Langworthy and Deuel[8] found that 93.4 per cent of raw tree-fern starch was assimilated by the human system. They also found that tests of samples of the feces gave no distinct blue color with iodin, which would seem to indicate that "the proportion of undigested starch was very small."

Although no digestion tests have been conducted with the cooked starch, it is thought that its digestibility is rather high, due to its large granules and its exceptionally easy conversion into soluble starch.

STARCH MAKING FROM THE TREE FERN

If the trunk of any of the different species of tree fern is cut crosswise, it will be found to contain a central starch core of 3 to 10 inches in diameter. Inclosing this core is a very hard, inner bark

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[7] Poi, which forms an important part of the native diet, is made from taro, which for the purpose is peeled, cooked, mashed, pounded, and then allowed to ferment slightly.

[8] Jour. Biol. Chem., 52 (1922), No. 1, p. 259. Digestibility of raw rice, arrowroot, canna, cassava, taro, tree-fern, and potato starches.

varying from one-fourth to one-half inch in thickness. The outer bark, which is 3 to 12 inches thick, is made up of coarse roots. These appear as air-feeding roots attached to the growing frond which die and form a part of the outer bark of the trunk.

An examination of the different species shows that *Cibotium chamissoi* contains a relatively large starch core and a thin exterior covering, and that even the largest specimens of *C. menziesii* contain a small core and a very thick outer bark (Pl. VII, fig. 1). Since the removal of the bark is a time-consuming operation at best, *C. chamissoi* is to be preferred, of the two varieties, for starch making, because it has a larger core and a thinner bark. It is preferable also because it contains no dextrins and other material which clog the shredding machine and prevent a complete sedimentation of the starch, as is the case with *C. menziesii.* The other species, due to their small size, contain cores too small to be of importance for starch production.

The first operation in securing the starch core is that of stripping off the outer fibrous bark as well as the inner shell. The bark is slabbed with a broad-bladed ax while the tree is standing, the workman beginning as near the top as he can reach and working down. As much as possible of the bark is removed while the tree stands. After the tree has been felled, the remainder of the bark is slabbed off. The core appears as a yellowish-white log, averaging 4 to 8 inches in diameter, 3 to 10 feet in length, and 30 to 100 pounds in weight (Pl. VII, fig. 2). The logs are then carried to the nearest road by donkeys and thence to the mill by truck. They should be milled within 36 hours after cutting to avoid hydrolysis and fermentation. Deterioration will not be so rapid if the inner bark is left on the log, but the already heavy cost of hauling will be increased by the added weight.

Experiments in preserving the starch log under water were not successful, due apparently to the partial hydrolysis of the starch into dextrins, with a resultant stickiness that interfered materially with the process of extraction.

A skilled workman, felling trees averaging 50 pounds to the starch core, should be able to cut about 1,000 pounds a day. Only 4 or 5 tons of starch core can be cut from an acre of *C. chamissoi*, since the mature trees alone are used for starch production.

Upon its arrival at the mill the starch core is cleansed of adhering soil and bark chips. It is then reduced to pulp by means of a power shredder. The shredder used in this investigation consists of a cylinder of sheet iron which has been fitted on a wooden core and given a roughened surface by having the perforations punched through from the inside. Water is used copiously during the shredding process to prevent the cylinder from becoming coated. The pulp is then run into a revolving screen, where it is sprayed with fresh water. The screen has a tendency to agitate and contains on its inner surface wooden cleats which facilitate washing the pulp free from starch. The milky starch water is run into wooden tanks of about 500-gallons capacity, and the starch is purified by sedimentation. The wet, purified starch is then put into sugar centrifuges, which remove a considerable part of the water at much less cost than would be involved in drying the starch by heat. A

rotary starch drier removes the remainder of the water. The dried starch is then powdered and put into 1-pound packages for market.

COST OF THE RAW MATERIAL

Strange as it may seem, the cost per ton of landing the starch core at the mill is greater than is the cost of production of most of the common starch crops in Hawaii. The following prices per ton prevail for landing the raw material at the mill at Hilo, Hawaii, from the tract located 4 miles north of the Volcano Road at 18 Miles: Cutting and stripping logs $6.50, making donkey trails and carrying logs to road $1, trucking to Hilo $3.50, total $11.

The first item is a fixed cost and could not be materially changed at the present wage scale in Hawaii. The making of donkey trails would increase in cost as it became necessary to exploit more remote areas; and shipping by rail to Hilo would not materially cheapen transportation charges since the main difficulty lies in getting the material from the forests to the main road. It is apparent, therefore, that the above listed items can not well be reduced under present conditions.

FUTURE OF THE INDUSTRY

The development of the tree-fern starch industry in Hawaii is seriously handicapped by the high cost of the raw material (starch core), and the very slow rate of growth of the tree which makes it impracticable to establish a permanent starch-producing area. The industry might become permanently established in Hawaii by marketing the starch as a special-purpose starch rather than in direct competition with cornstarch as a food, or with potato starch for industrial uses. The amount used for special purposes would, of course, be limited, but the market price could be placed sufficiently high to compensate for the high cost of raw material.

In considering the possibilities of this industry in other tropical countries, it is important to bear in mind that a very large percentage of the total cost of production is for labor. Only a small capital is required to start the industry. The tree-fern lands are usually of very little value for any other purpose, and can be leased at a nominal rental; and the starch extraction machinery is relatively inexpensive. The actual starch extraction process costs less than a cent a pound of finished product. It is evident, therefore, that in countries where labor costs are only a fraction of what they are in Hawaii the cost of producing tree-fern starch could be greatly reduced and might well be brought to a sufficiently low figure to permit of commercial production. This is, of course, based on the assumption that the species of tree ferns found elsewhere are equally as well adapted to starch production as is *Cibotium chamissoi.*

SUMMARY

The Hawaiian Islands contain many thousands of acres of tree-fern forests from which starch can be extracted.

Three species are found in Hawaii, only one of which, Hapu (*Cibotium chamissoi*), is used for starch production.

Experiments in propagation of the tree fern show that not only the crowns, but also the large and the small lateral shoots, and undeveloped buds on the trunk, may be successfully planted. An average of three plantings or sets can be secured from each mature tree fern.

The station developed a method for determining the rate of growth of the tree fern. This method showed the vertical growth to be only 4.35 inches a year, which means that it would require 20 years for a tree fern to reach sufficient size for starch production. Such a slow rate of growth makes it commercially impracticable to plant cuttings from different parts of the tree fern, or to build permanent roads or fences for the purpose of obtaining the raw material.

The high costs involved in securing raw material preclude the possibility of the starch becoming a competitor with the common commercial starches, and likewise limit its use to special purposes commanding a high market price. With the cheap labor available in many of the tropical countries, however, the costs could be reduced to a fraction of what they are in Hawaii.

In chemical composition the core of the tree fern is similar to that of other starch crops, especially of edible canna.

Morphologically, the starches of the different species of tree ferns are very similar, differing chiefly in size, but also somewhat in shape.

Tree-fern starch is used both as a food and for laundry purposes. It is markedly superior to cornstarch for laundry purposes. In Hawaii the starch is used chiefly in the preparation of poi.

Although the development of the tree-fern starch industry is seriously handicapped by the high cost of securing the raw material, data have been secured which would make possible, in cases of emergency, the production on short notice of sufficient starch to meet the need of the local population.

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